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# An Analysis on Risk Factors of Coronary Heart Disease Using Simple and Weighted Fuzzy Cognitive Map

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***Abstract.*** Coronary heart disease (CHD) is a major and leading cause of morbidity and mortality among adults. Factors like blood pressure, cigarette smoking, cholesterol, diabetes, obesity, unhealthy food habit, stress and family history of premature CHD have been considered in defining CHD risk directly and indirectly. In this study, a new approach based on fuzzy cognitive map (FCM) is introduced to model and stimulate the risk factors of heart disease. To identify the impact factors relevant to the goal, a FCM is built and then analyzed. To analyze this problem, two cases as simple FCM and weighted FCM are considered. Simple FCM shows how the determined factors affect the goal and a hidden pattern. Weighted FCM is used to clearly measure the composite effects resulting from changes of multiple factors. Hence, this is the non-statistical approach to study the problem with imprecise information.

***Keywords:*** coronary heart disease, fuzzy cognitive maps, weighted FCM, simple FCM

***AMS Mathematics Subjects Classifications (2010):*** 03B52, 68T35

## 1. Introduction

A Coronary Heart Disease (CHD) is a disease where one or more of the arteries supplying blood to the heart muscle become blocked. Blockage of these arteries means that some of the heart muscle becomes deprived of oxygen, which results in angina or a heart attack. Coronary heart disease continues to be a leading cause of morbidity and mortality among adults in the world. Several factors such as genetic, metabolic, early-life, conventional and non-conventional risk factors were suspected to cause high CHD morbidity and mortality rates among adults [7,10,11].

Risk factors have included blood pressure, cigarette smoking, cholesterol (TC), LDL-C, HDL-C, and diabetes [10]. Factors such as obesity, left ventricular hypertrophy, family history of premature CHD, and ERT have also been considered in defining CHD risk [11]. Data from population studies enabled prediction of CHD during a follow-up interval of several years, based on blood pressure, smoking history, TC and HDL-C levels, diabetes, and left ventricular hypertrophy on the ECG. These prediction algorithms have been adapted to simplified score sheets that allow physicians to estimate multivariable CHD risk in middle-aged patients [7].

There are many risk factors associated with coronary heart disease. Some risk factors such as family history, ethnicity and age, cannot be changed. Other risk factors that can be treated or changed include tobacco exposure, high blood pressure (hypertension), high cholesterol, obesity, physical inactivity, diabetes, unhealthy diets, and harmful use of alcohol. Of particular significance in developing countries is the fact that while they are grappling with increasing rates of cardiovascular disease, they still face the scourges of poor nutrition and infectious disease. Cardiovascular disease is the leading cause of death in the developing world [1].

Hypertension plays a significant role in heart attacks. Abnormal blood lipid levels, that is high total cholesterol, high levels of triglycerides, high levels of low-density lipoprotein or low levels of high-density lipoprotein (HDL) cholesterol all increase the risk of heart disease [14]. Tobacco use, whether it is smoking or chewing tobacco, increases risks of cardiovascular disease. Passive smoking is also a risk factor for cardiovascular disease. Physical inactivity increases the risk of heart disease by 50%. Obesity is a major risk for cardiovascular disease and predisposes to diabetes. Diabetes is a risk factor for cardiovascular disease. Type2 diabetes is a major risk factor for coronary heart disease. A diet high in saturated fat increases the risk of heart disease. It is estimated to cause about 31% of coronary heart disease and 11% of stroke worldwide. A chronically stressful life, social isolation, anxiety and depression increase the risk of heart disease and stroke. Having one to two alcohol drinks a day may lead to a 30% reduction in heart disease, but above this level alcohol consumption will damage the heart muscle [2, 18]. Genetic factors likely play some role in high blood pressure, heart disease, and other vascular conditions. However, it is also likely people with a family history of heart disease share common environments and risk factors that increase their risk. The risk for heart disease can increase even more when heredity is combined with unhealthy lifestyle choices, such as smoking cigarettes and eating a poor diet [9].

Cardiovascular diseases are major causes of mortality and disease in the Indian subcontinent, causing more than 25% of deaths. It has been predicted that these diseases will increase rapidly in India and this country will be host to more than half the cases of heart disease in the world within the next 15 years. Coronary heart disease and stroke have increased in both urban and rural areas. Epidemiologists in India and international agencies, such as the World Health Organization (WHO), have been sounding an alarm on the rapidly rising burdens of CHD for the past 15 years [6,12,17]. The reported prevalence of coronary heart disease (CHD) in adult surveys has risen 4-fold over the last 40 years (to a present level of around 10%), and even in rural areas the prevalence has doubled over the past 30 years (to a present level of around 4%). India is undergoing a rapid health transition with rising burden of coronary heart disease (CHD). Studies among Indian migrants in various parts of the world have documented an increased susceptibility to CHD in comparison to the native population studied [3,8,10,12,18].

This article is organized as follows: Section 2 gives an introduction to FCM. Section 3 presents FCM procedure used for this study consisting of concepts and definitions and algorithm. Modeling of problem and Simulation analysis are presented in Section 4. Concluding remarks are drawn in Section 5.

## 2. An overview of FCM

FCMs are fuzzy structures that strongly resemble neural networks. These structures have powerful and far-reaching consequences as a mathematical tool for modeling complex systems (Vasantha Kandasamy & Smarandache, 2003). The FCMs were first introduced by Kosko(1986). It was a fuzzy extension of the cognitive maps. The cognitive maps were introduced in 1976 by Axelord(1976).

In fact, a FCM incorporates the accumulated experience and knowledge about the system operation by using of human experts that know the system operation and system behavior in different situations. It must be mentioned that experts play very critical role in the designing and development of FCMs. Experts who have knowledge and experience of the system operation and behavior determine concepts, interconnections and assigning casual fuzzy weights to the interconnections. FCMs have been successfully used in decision making and simulation of complex situation. There are over a hundred research papers which deal with FCMs. This tool has been used to study real world situations. Vasantha Kandasamy and RamKishore (1999) have adopted the FCM in case of symptom-disease model in children.

Ozesmi (1999) has used FCM to study the ecosystems of the delta wetlands in Turkey using expert opinions. Lee, Lee, Kwon, Han and Yu(1998) used the mechanism of integrating FCM knowledge with a strategic planning simulation where a FCM helps the decision makers understand the complex dynamics between a certain strategic goal and the related environmental factors.

## 3. Method: The FCM Procedure

FCMs are fuzzy signed directed graphs with feedback. There are many casual feedback loops in FCMs. Feedback prevent the graph-search techniques used in artificial-intelligence expert systems. By existence feedback, experts can freely draw casual graphs of their problems and permit casual adaptation laws, conclude casual links from simple data. FCMs can be observed a dynamical system and equilibrium behavior can be interpreted as a forward-evolved inference.

### 3.1. Simple FCM

FCM is composed of nodes and edges. There are concepts like policies, events etc. as nodes and causalities as edges. The graph represents causal relationship between concepts. The nodes of the FCM can be selected from fuzzy sets. The directed edge $e_{ij}$ from causal concept $C_i$ to the concept $C_j$ measures how much $C_i$ causes $C_j$ . The edge can be signed as follows: if increase (or decrease) in concept $C_i$ direct to increase (or decrease) in concept $C_j$ then causality between two concepts is positive. If there is no relation between two concepts then there exists no causality. If increase (or decrease) in concept $C_i$ direct to decrease (or increase) in concepts $C_j$ then causality between two concepts is negative. FCMs with edge weights or causalities from the set {-1, 0, 1} are called simple FCMs. In simple FCMs, edges can be signed as follows:

Positive causality is signed by $e_{ij} = +1$.

Negative causality is signed by $e_{ij} = -1$.

Non-causality is shown by $e_{ij} = 0$.

By simple FCMs, a quick first approximation is given to an expert stand or printed causal knowledge (Vasantha Kandasamy & Smarandache, 2003). The adjacency matrix or connection matrix of the FCM is defined by $E = [e_{ij}]_{NxN}$ , where N is concepts numbers. An expert can use the adjacency matrix to list the cause and effect relationships between the nodes. In a FCM, instantaneous state ($A = [a_{ij}]_{1xN}$ ) indicates the on-off position of the node at an instant.

If $a_i$ = off ; then $a_i = 0$.
If $a_i$ = off ; then $a_i = 0$. for i = 1,2, . . . ,n.

The threshold function used to bound the transformation to a limit cycle. This threshold function is a sign function defined with the following functionality:

$$f(x) = \begin{cases} -1, & x < 0 \\ 0, & x = 0 \\ 1, & x > 0 \end{cases}$$

An FCM with feedback has cycles. Cyclic FCM possesses at least a directed cycle and acyclic FCM does not possess any directed cycle. Dynamical system is an FCM with feedback, in this system causal relations flow through a cycle in a revolutionary way. The equilibrium for this dynamical system is called the hidden pattern. If the equilibrium state of a dynamical system is a unique state vector, then it is called a fixed point. The algorithm for performing FCM is given as follows:

Step 1: Read the input vector A(t).
Step 2: Give the connection matrix E.
Step 3: Calculate the output vector O(t) = A(t) * E.
Step 4: Apply threshold to output vector: O(t) $\cong$ A(t+1).
Step 5: If A(t+1) = A(t) , stop else go to step 1.
End.

**3.2. Weighted FCM**

In this weighted FCM, the expert expected to determine a weighted connection matrix. We asked the experts to determine the relations between concepts with values from [-1,+1]. These relationships could be determined from the following procedure:

If relation between concept i from row and concept j from column is determined as +1 in the simple connection matrix then we asked the expert to determine the value of this relation from (0, +1]. For example, if row 2, column 1 component has been determined as +1 in simple FCM and the expert claimed that increase or decrease in row 2 could affect directly 50% on column 1. Therefore, this claim could be determined as +0.5 as the weight of this relation.

If the relation between the concept i from row and concept j from column is determined as -1 in the simple connection matrix then we asked the expert to determine the value of this relation from [-1,0). For example, if row 3, column 2 component has been determined as -1 in simple FCM and the expert claimed that increase or decrease in row 3 could have reverse affect of about 40%on column 2. Therefore, this claim could be determined as -0.4 as the weight of this relation. The weighted connection matrix is then used for further analysis.

## 4. Experiments and results

In this study we have modeled and simulated risk factors of coronary heart disease based on FCM. We asked an expert to define important factors that have influence on coronary heart disease. Our expert defined 10 risk factors and 1 output factor introduced as "defined concepts of FCM", as shown in Table 1.

**Table 1:** The defined concepts for FCM.

| Node No. | Concepts | Type of factors |
|---|---|---|
| C1 | High Blood Cholesterol | risk |
| C2 | High Blood Pressure (Hypertension) | risk |
| C3 | Body Weight | risk |
| C4 | Exercise | risk |
| C5 | Unhealthy Food Habit | risk |
| C6 | Smoking | risk |
| C7 | Alcohol Use | risk |
| C8 | Diabetes | risk |
| C9 | Stress | risk |
| C10 | Family History of CHD | risk |
| C11 | Risk of Heart Disease | Output |

All risk factors of CHD can be classified into two categories: modifiable and non-modifiable factors. Factors such as Family History of CHD, Diabetes, age, race etc., are non-modifiable factors and the remaining are modifiable factors. To identify the key risk factors to assess the heart disease, a FCM should be built and then analyzed. These defined concepts of FCM are considered as graph nodes.

As mentioned, two cases are to be analyzed. In case 1 the selected expert determines simple values as {-1, 0, 1} for connections. By this approach, one can study how determined factors affect on output. A hidden pattern is obtained by this case. In case 2, expert determines weighted values for connections. By this case, the model can be analyzed by changes of factors value. The structure is elaborated in the following two subsections.

### 4.1. Case 1: Simple FCM

There are 11 nodes to be used and an expert opinion is obtained. As mentioned, the connection matrix for simple FCM is shown in Table 2. Also, the directed graph for the expert opinion can be obtained by using the corresponding relational matrix, as shown in Fig. 1.

Consider the first node C4 = 1. This node can be observed as "Exercise" in Table 1. It will be shown how exercise can affect on Heart disease. Threshold signal functions synchronously update each concept after each pass, through the connection matrix E.

| Cause | Effects | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 |
| C1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| C2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| C3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| C4 | -1 | -1 | -1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -1 |
| C5 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| C6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| C7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| C8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| C9 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 |
| C10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| C11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 2 :** Simple FCM connection matrix E

| Cause | Effects | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 |
| C1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.60 |
| C2 | 0.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.55 |
| C3 | 0 | 0.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.35 |
| C4 | -0.15 | -0.2 | -0.3 | 0 | 0 | 0 | 0 | -0.45 | 0 | 0 | -0.45 |
| C5 | 0.5 | 0.8 | 0.6 | 0 | 0 | 0 | 0 | 0.3 | 0 | 0 | 0.00 |
| C6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.40 |
| C7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.20 |
| C8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.3 | 0 | 0.35 |
| C9 | 0 | 0.6 | 0 | 0 | 0 | 0.2 | 0.2 | 0.6 | 0 | 0 | 0.35 |
| C10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.20 |
| C11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |

**Table 3:** Weighted FCM connection matrix

The process is started by the following vector:

A1 = (0,0,0,1,0,0,0,0,0,0,0)

B1 = A1* E = (-1,-1,-1,0,0,0,0,-1,0,0,-1)

$$\to (-1,-1,-1,1,0,0,0,-1,0,0,-1) = A2$$

where symbol '→' means the resultant vector has reached threshold and updated.

B2 = A2 * E = (-2,-2,-1,0,0,0,0,-1,-1,0,-1)

$$\to (-1,-1,-1,1,0,0,0,-1,-1,0,-1) = A3$$

B3 = A3 * E = (-2,-3,-1,0,0,-1,-1,-2,-1,0,-6)

$$\to (-1,-1,-1,1,0,-1,-1,-1,-1,0,-1) = A4$$

B4 = A4 * E = (-2,-3,-1,0,0,-1,-1,-2,-1,0,-8)

$$\rightarrow (-1,-1,-1,1,0,-1,-1,-1,-1,0,-1) = A5 = A4 \quad \text{----------} \quad (1)$$

It was observed that A4 = A5. Therefore, a fixed point is obtained. Thus, at the end of process, we can infer that increase in the factor ‘exercise’ eventually leads to decrease in heart disease.

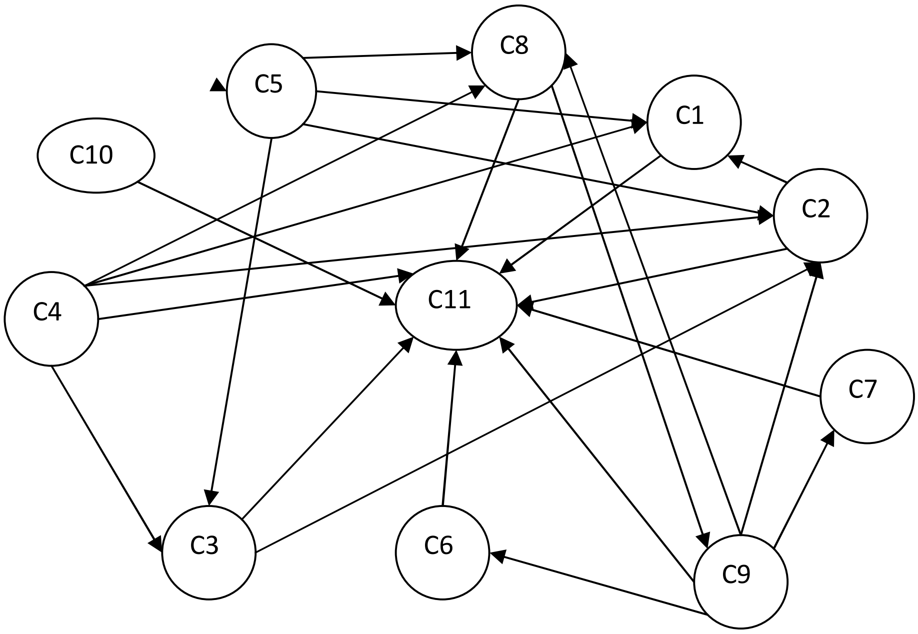


**Figure 1:** The directed graph for the expert opinion

**4.2. Case II: Weighted FCM**

In this case, an expert gives weighted connection matrix. This matrix is represented in Table 3. In addition, the FCM matrix can be used usefully for clearly measuring the composite effects resulting from changes of multiple factors. For example, consider two situations:

**Situation 1:** Suppose that three factors changed. Then stimulus input vector may be obtained as follows:

Stimulus Input
Exercise C4 = 0.8
Smoking C6 = -0.8
Stress C9 = -0.9

This information can be organized into stimulus input vector1.
Stimulus vector 1 = (0, 0, 0, 0.8, 0, -0.8, 0, 0,-0.9, 0, 0)

Therefore multiplying this stimulus input vector with FCM matrix, a consequence vector can be obtained as follows:

Stimulus vector i * weighted matrix = stimulus vector (i + 1)

Therefore, stimulus vector 2 can be obtained using the above equation as follows:

Stimulus vector 2 = (-0.12,-0.7,-0.24, 0, 0,-0.18,-0.18,-0.9, 0, 0,-0.995)

It can be observed from the above that considered changes can vary some concepts as follows:

Cholesterol= -0.12
Blood pressure = -0.7
Bodyweight = -0.24
Smoking = -0.18
Alcohol use = -0.18
Diabetes = -0.9
Risk of heart disease= -0.995

Then a consequence vector may be obtained as follows.

Consequence vector = (0,-0.005,0,0,0,-0.002,-0.002,-0.005,0,0,-0.009) may be interpreted such that changes in those three factors including exercise, smoking, and stress affect risk of heart disease negatively by -0.009, blood pressure negatively by -0.005 and so on. Therefore, we conclude that changes of three factors may reduce the risk of heart disease.

**Situation 2:** If three factors change including bodyweight, exercise, and unhealthy food habit, stimulus input vector 1 can be organized as follows.

Stimulus vector 1 = ( 0, 0, 0.5, -0.6, 0.4, 0, 0, 0, 0, 0,0)

Then a consequence vector may be obtained as follows.

Consequence vector = (0.09, 0.07, 0,0,0,0.02, 0.02, 0.12, 0, 0, 0.35)

Consequence vector show composite effect of stimulus input vectors on the risk of heart disease is +0.35 which means that changes of these factors may affect the risk of heart disease positively by 0.35.

By this way, one can analysis different scenarios viewpoint of risk factors of a heart disease and determine key factors. After determining key factors, more factors can be considered.

## 5. Conclusion

Simulation can be used in a wide range of applications in health sciences. Many factors affect the risk of heart disease directly and indirectly. In this study, a new approach based on FCM was introduced to model the risk factors of heart disease. It was studied how determined factors by an expert affect the risk of heart disease. To identify the key factors relevant to the risk, a FCM was built and then analyzed. To analyze defined system, two cases as simple FCM and weighted FCM were considered.

Simple FCM showed how determined factors affect on the risk. For example, we analyzed how exercise can affect on the risk of heart disease. Therefore, by the proposed approach, we inferred how exercise vary cholesterol, blood pressure, body weight, smoking, alcohol use, diabetes, stress and risk of heart disease. Therefore, a hidden pattern was obtained using simple FCM. Equation (1) demonstrate that the increase of exercise eventually leads to decrease not only in the risk of heart disease but also decrease in the level of cholesterol, blood pressure, diabetes, body weight and stress. Thus, the FCM provides the hidden pattern. Other methods cannot provide these results with the unsupervised data.

Also, weighted FCM was used usefully for clearly measuring the composite effects resulting from changes of multiple factors. This application was shown by two different situations. In the first situation, the changes of three factors including exercise (0.8), smoking (-0.8), stress (-0.9) affect the risk of heart disease negatively by -0.009. That is, if exercise is increased, smoking is reduced and removing stress by relaxing then the risk of heart disease is reduced. In situation 2, it was assumed that the changes of three factors including body weight (0.5), exercise (-0.6), unhealthy food habit (0.4) affect the risk of heart disease positively by 0.35, cholesterol by 0.09, blood pressure by 0.07 and diabetics by 0.12. That is, if the body weight is increased, exercise is decreased, and unhealthy food habit is increased then the risk of heart attack is increased. Also, the level of cholesterol, blood pressure, and blood sugar are increased.

From this analysis, the most influential and effective factor is ‘exercise’. That is, physical inactivity is the most impactful factor in the risk of heart disease. Also, this physical inactivity or sedentary life style is the major cause for high cholesterol, high blood pressure, obesity, diabetes, stress and the risk of heart attack.

The proposed FCM approach is capable of simulating and modeling the risk factors of heart disease. Moreover, this proposed approach leads to identification of the key factors related to objective of the FCM model.

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